The Multi-Pinch Experiment as first step towards PROTO-SPHERA

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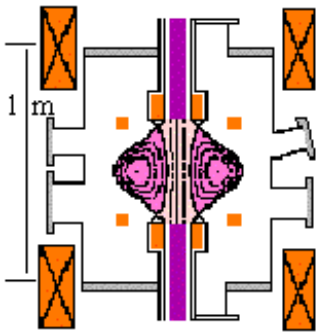
Outline

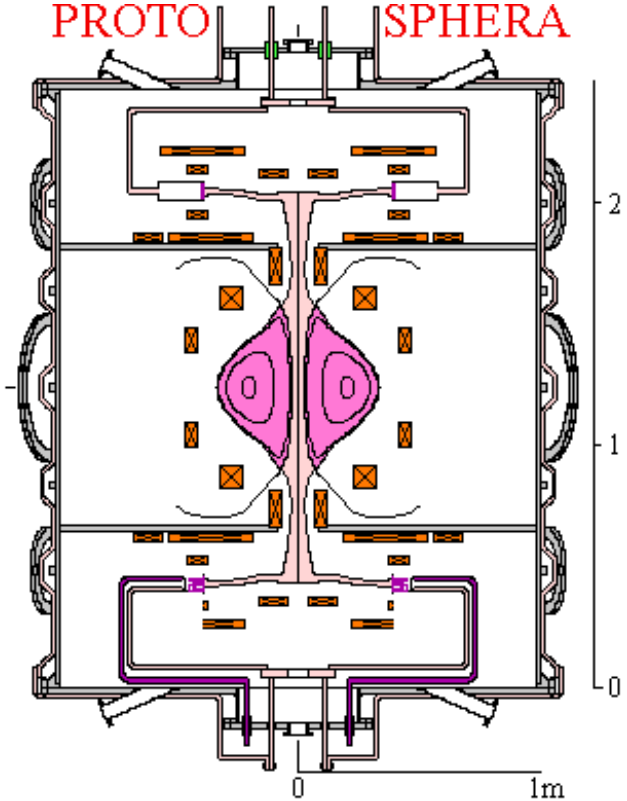
- **PROTO-SPHERA purpose & aims**
- **Theoretical basis & analysis**
- **Multi-Pinch: the first phase of PROTO-SPHERA**
- **Conclusions**

PROTO-SPHERA

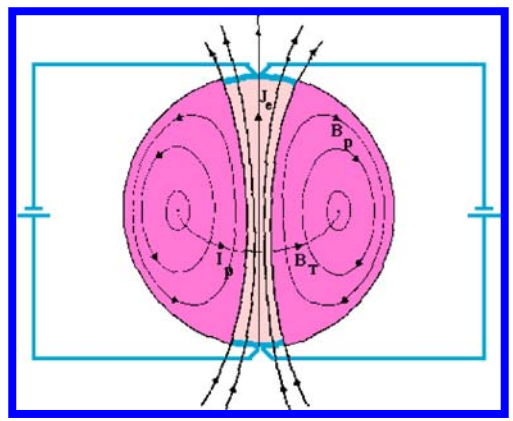
TS-3



PROTO SPHERA



Aims at producing a spherical torus (ST) with a screw pinch (SP) replacing the centerpost



$I_e, I_p = 40, 50$ kA	pinch, ST currents	$I_e, I_p = 60, 240$ kA
$A = 1.6$	aspect ratio	$A \leq 1.3$
$\tau_{pulse} = 80\ \mu s \sim 110\ \tau_A$	pulse duration	$\tau_{pulse} \geq 70$ ms $\sim 1\ \tau_R$

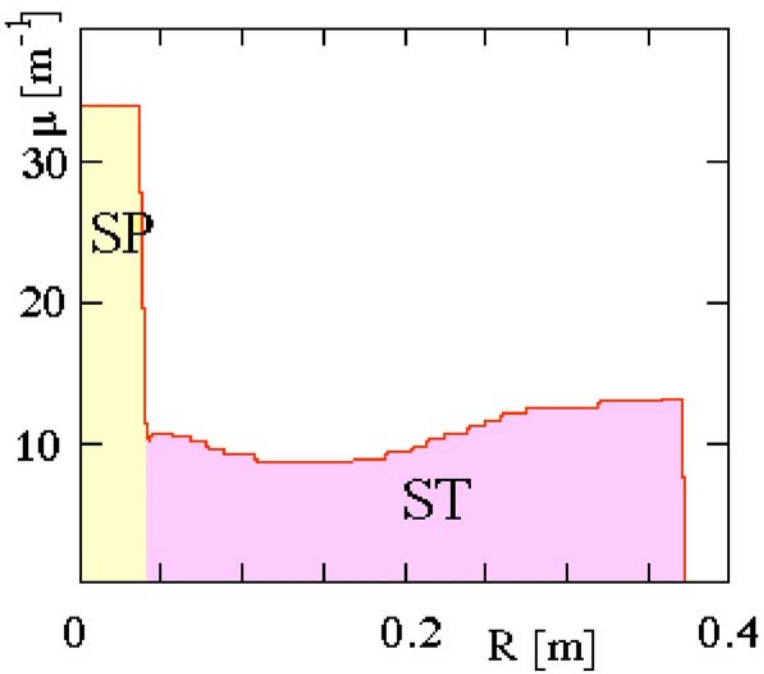
Goals: sustain the plasma (Helicity Injection SP⇒ST) for more than $\tau_R=\mu_0 a^2/\eta$ (resistive time) and compare τ_E with START

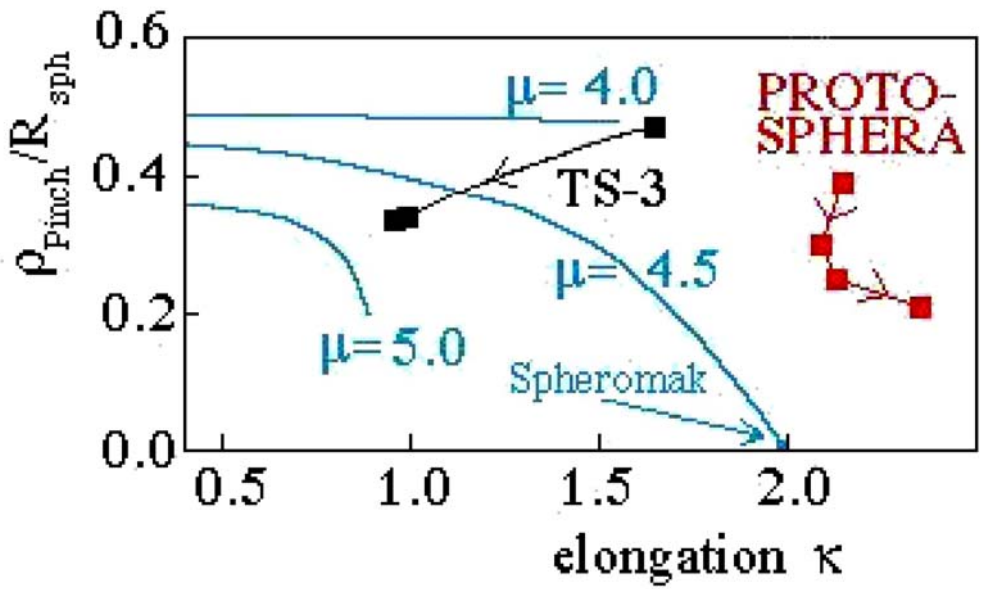
PROTO-SPHERA & Spheromaks (TS-3)

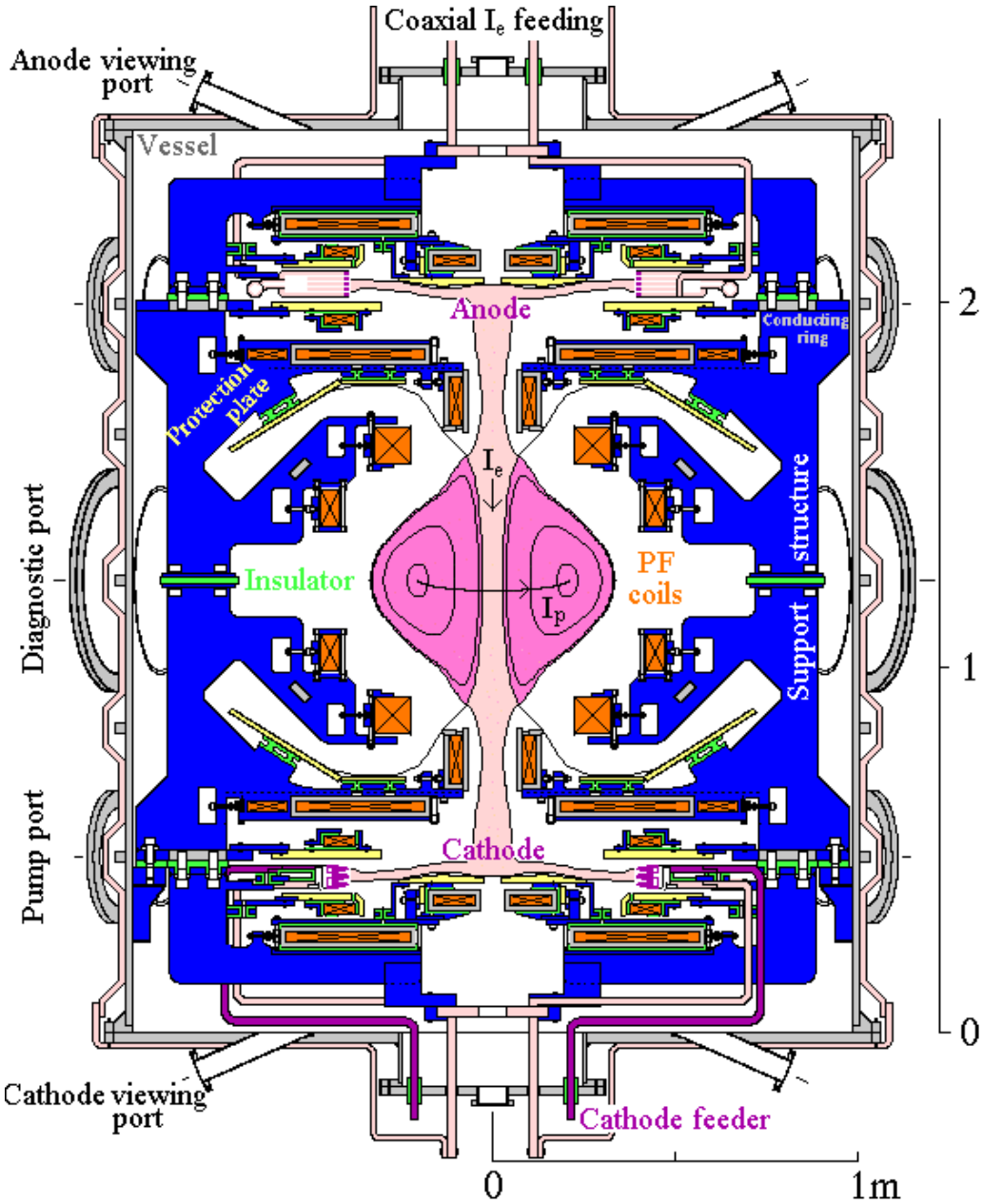
Two important requirements are different for the PROTO-SPHERA equilibria with respect to Flux-Core-Spheromaks like TS-3:

1) Tokamak-like safety factor profile of ST: $q_0 \sim 0.94$, $q_{95} \sim 2.6$ at the edge
2) Strong jump of the surface averaged relaxation parameter $\langle\mu\rangle=\mu_0\langle \mathbf{j}\cdot\mathbf{B}/B^2\rangle$ between SP and ST $\Rightarrow$ Helicity Injection ($\mu \sim 35\ m^{-1}$ inside SP, $\mu \sim 10\ m^{-1}$ inside ST)

PROTO-SPHERA (R_{sph}=0.35 m) has been designed in order to be as far as possible from the pure Spheromak $\mu_{ST}R_{sph} \leq 4.49$ eigenvalue







Physics & Engineering Design

ST diameter = 0.7 m

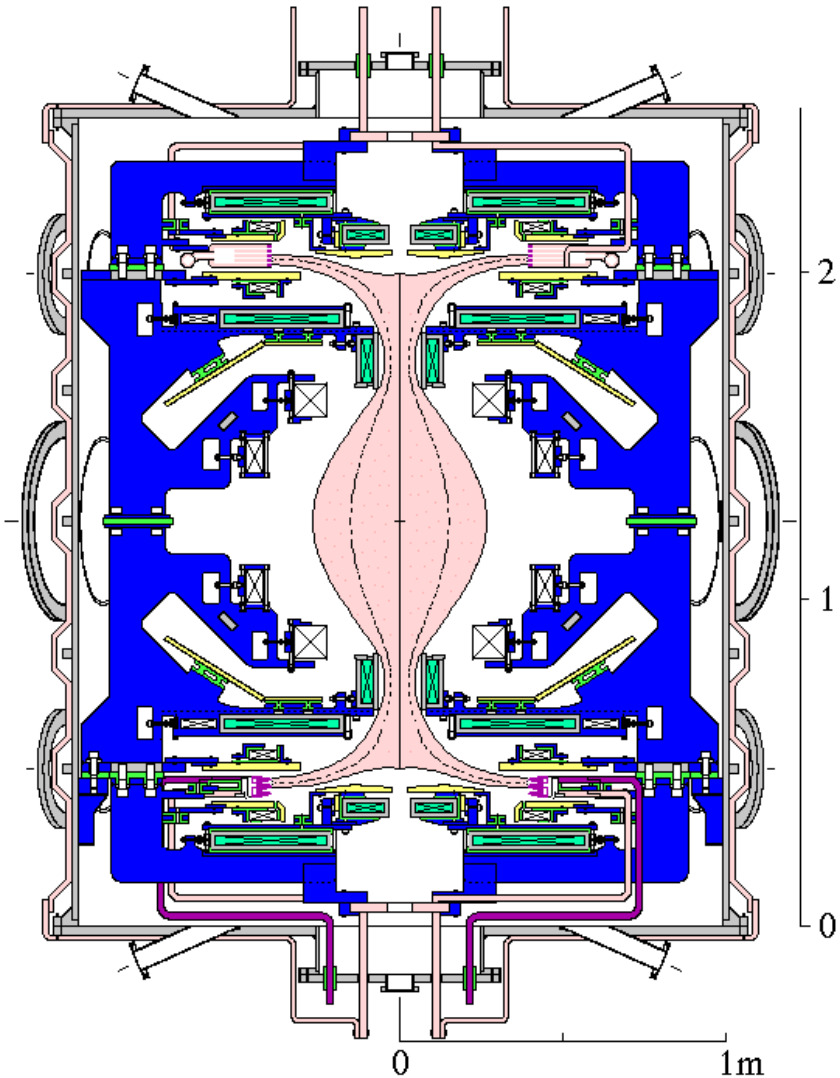
Toroidal plasma current
I_p = 240 kA

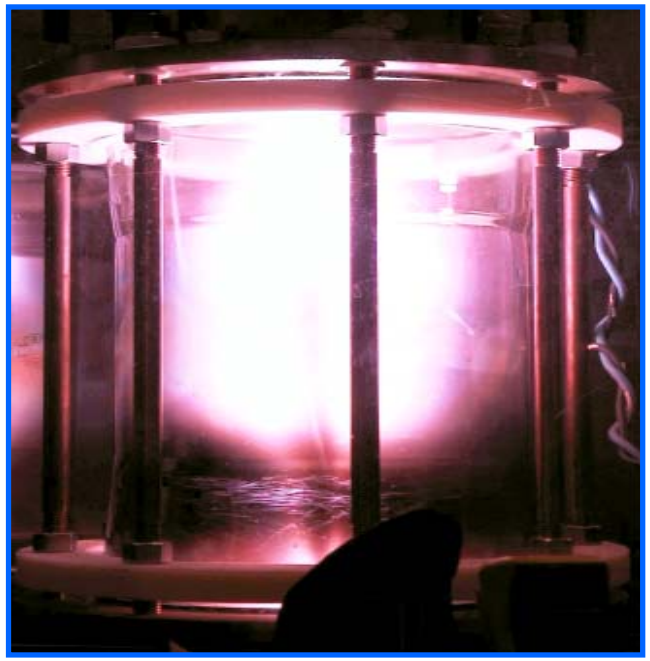
Aspect ratio A = 1.2
Elongation κ = 2.35

Pinch current
I_e = 60 kA

Engineering design complete (geometry, stresses and temperatures)

Main Breakdown features





Proto-Pinch

Testbench

(I_e~ 700 A)

⇐

Screw Pinch (SP)
formed by a hot cathode breakdown

- Filling pressure p_H~10^{-3}÷10^{-2} mbar
- Cathode filaments (W) heated to 2600 °C
- V_e~100 V applied on the anode
- Electrode arc current limited to I_e~8.5 kA

Theoretical analysis of the PROTO-SPHERA configuration

Equilibria:

- formation phase fully analyzed
- equilibrium resilience checked by varing the functional forms of $p(\psi)$ & $f(\psi)$

both on the SP and on the ST $\Rightarrow$ All equilibria has been obtained with the same coils set

Stability:

- New free boundary ideal MHD code developed $\Rightarrow$ plasmas extending up to the symmetry axis (R=0) with regular ($|B| \neq 0$) & singular ($|B|=0$) X-points

Investigation about the resistive MHD instabilities, evaluation of the Helicity Injection efficency both from a macroscopic as well as a microscopic point of view are in progress

PROTO-SPHERA Stability Results

n=1,2,3 investigated for all equilibria
Main constraint I_{ST}/I_e

Stability obtained for:

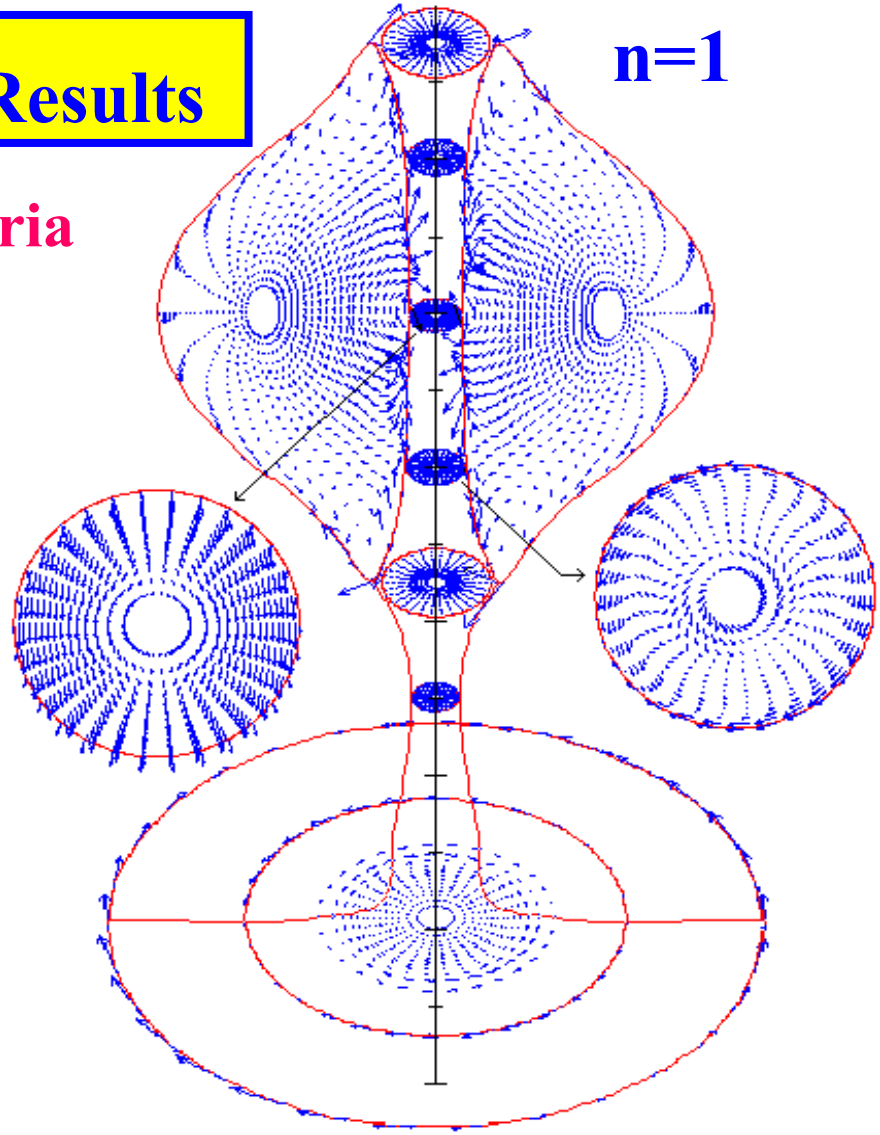
- $\beta = 21 \div 26\%$, $I_{ST}/I_e = 0.5 - 1$
- $\beta = 14 \div 15\%$, $I_{ST}/I_e = 2-4$

With $\beta_{T0}=2\mu_0\langle p\rangle_{vol}/\langle B_{T0}^2\rangle_{vol}$

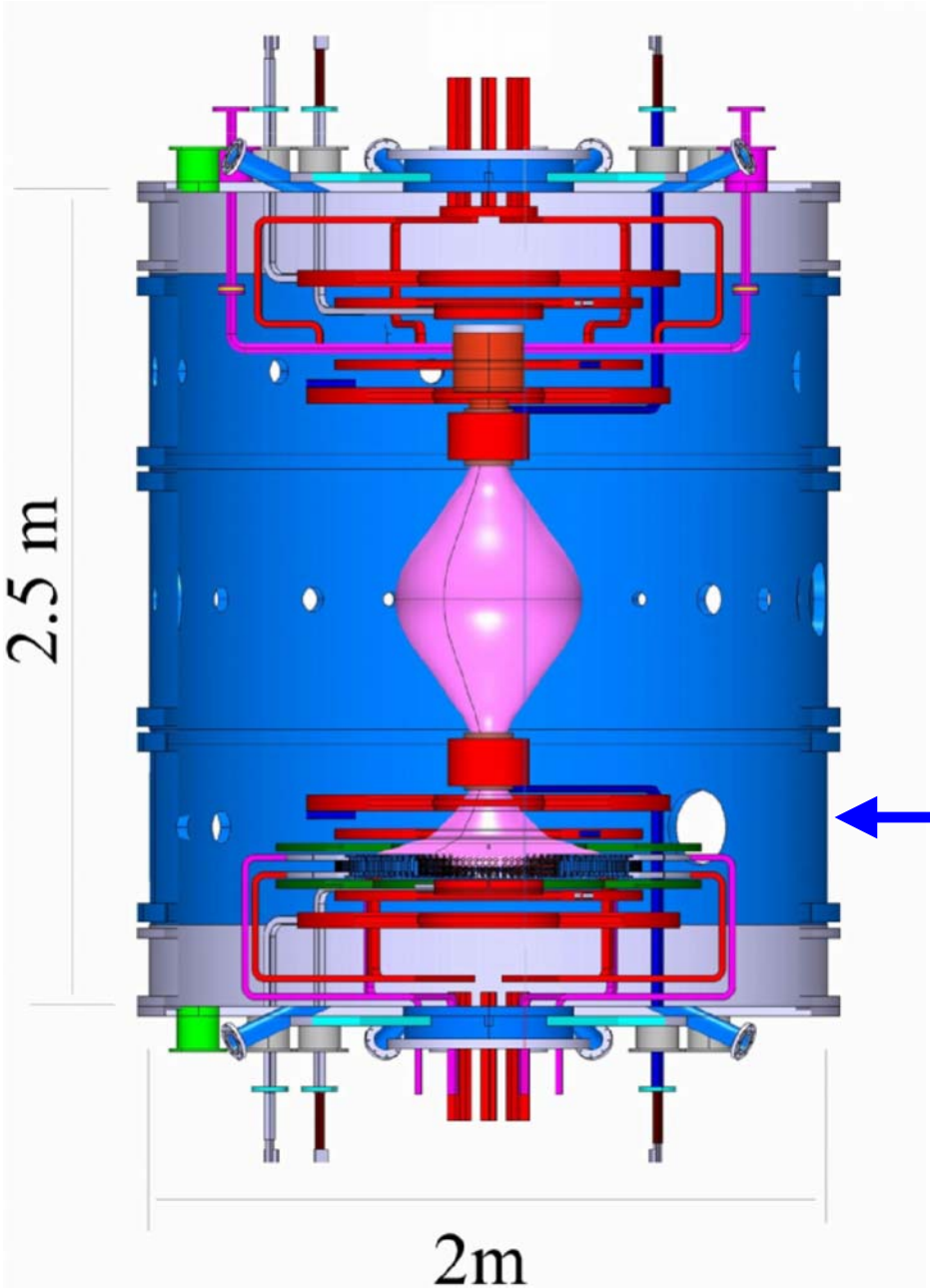
- $\beta_{T0}=28 \div 29\%$, $I_{ST}/I_e = 0.5 - 1$
- $\beta_{T0}=72 \div 84\%$, $I_{ST}/I_e = 2-4$

The dominant instabilities are:

- **up to $I_{ST}/I_e \approx 3$ Spherical Torus instabilities**
- **$I_{ST}/I_e > 3$ Screw Pinch kink instabilities**



$I_{ST}/I_e = 5$ and $\beta \approx 15\%$
Unstable



Multi-Pinch Experiment

Aims:

Stable Screw Pinch plasma with the full dimension and disk shape, but reduced current I_e (2.7 Vs. 8.5 kA)

Philosophy:

Almost all parts should be reutilized in PROTO-SPHERA

START vacuum vessel
(In Frascati since May 2004)

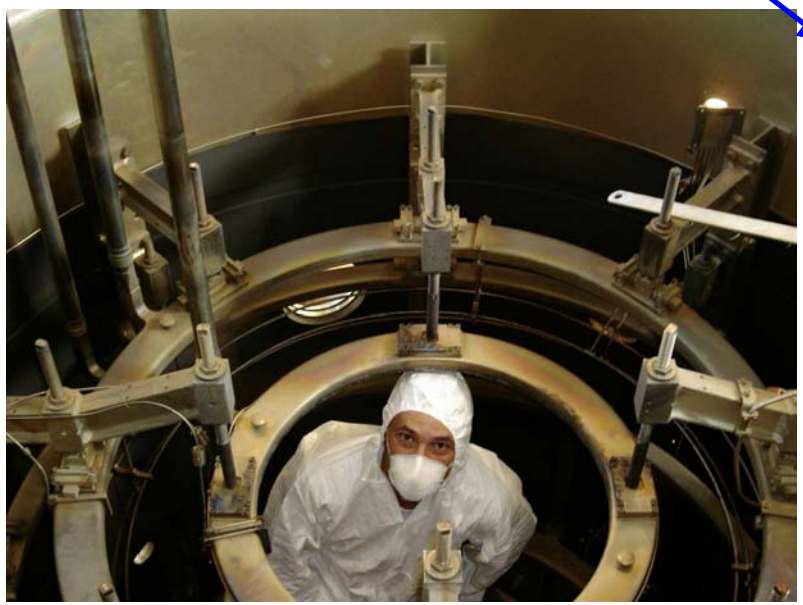
- **Simplified PF coils system with constant current:**
  under construction in Ansaldo (Genova, Italy), fully recoverable for PROTO-SPHERA
- **Fed with 0.6 kA, 120 V (no water cooling)**

  (1.9 kA, 350 V in PROTO-SPHERA)

START in Frascati

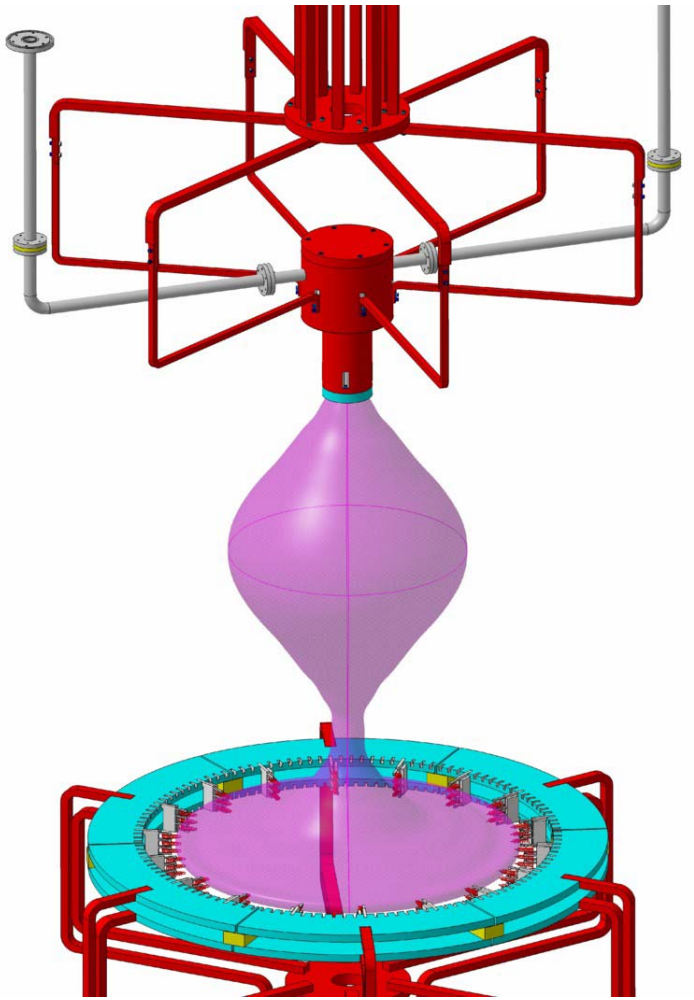
Arrival
May 2004

Disassembling
October 2004

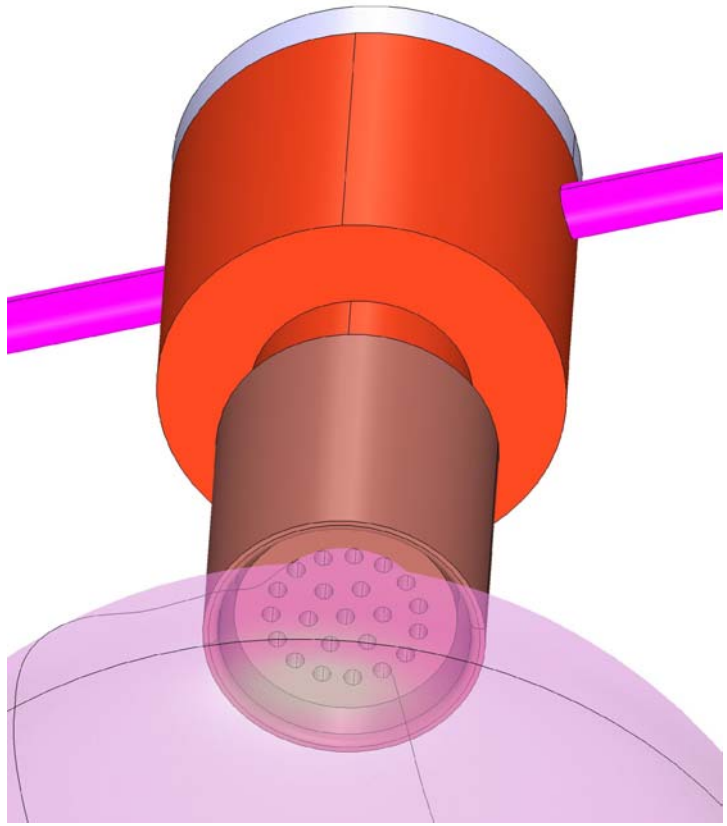


Multi-Pinch Experiment
(first phase)

Cathode plasma only is disk-shaped

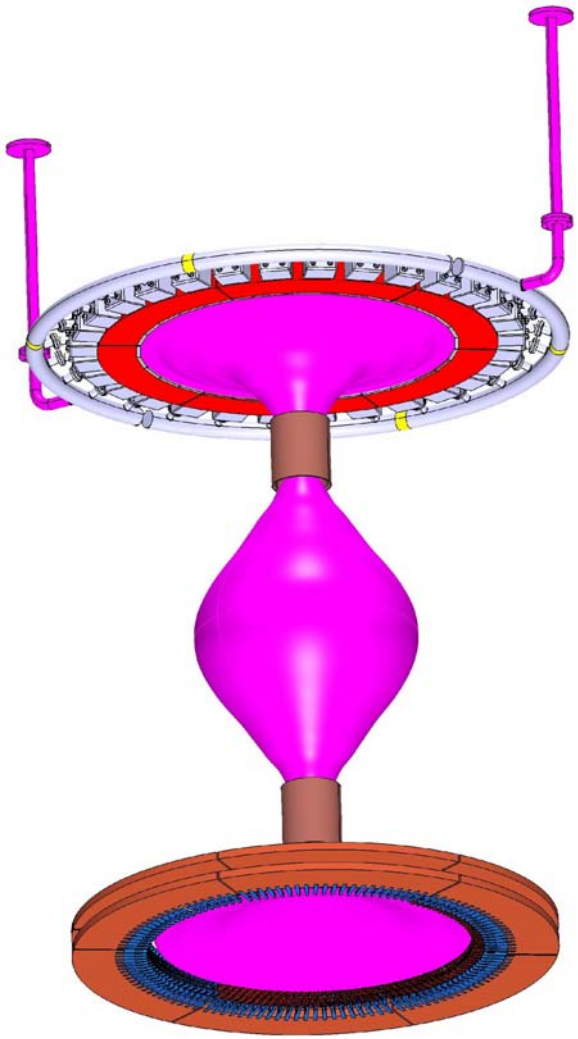


Power density on the "single" anode ~ PROTO-SPHERA



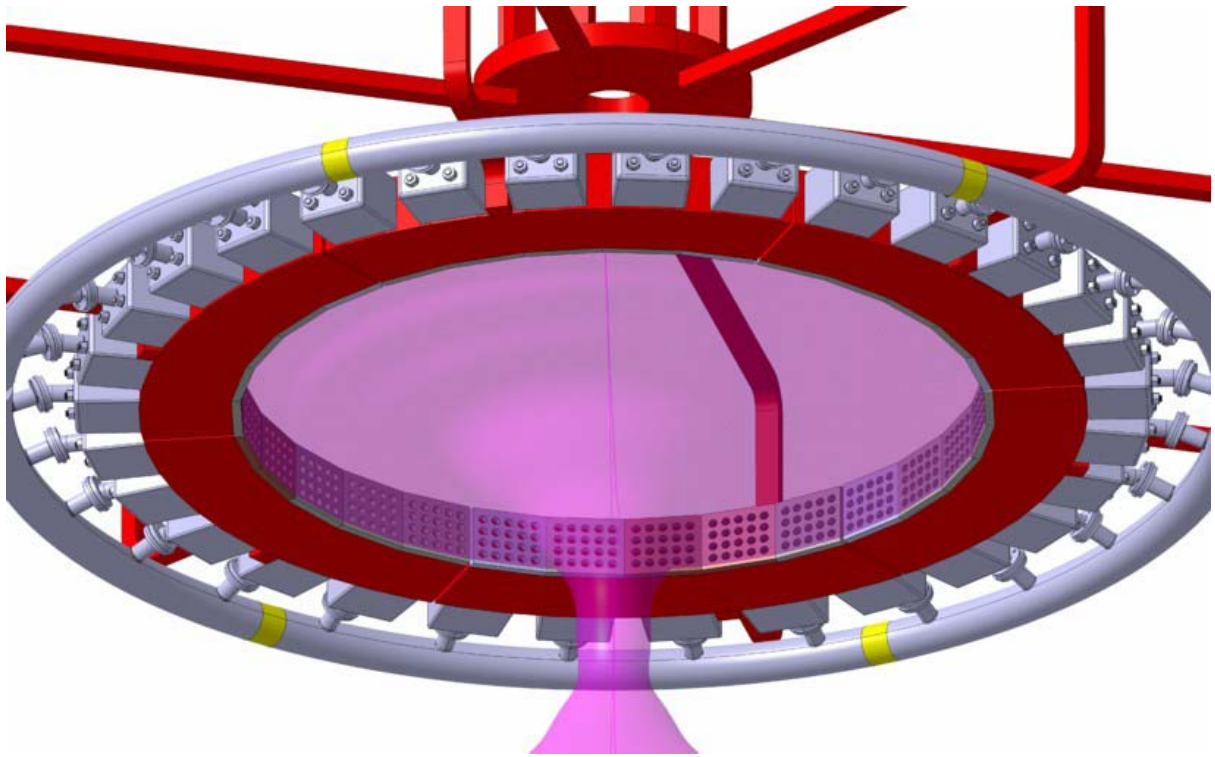
Multi-Pinch Experiment
(second phase)

Anode & Cathode plasma disk-shaped



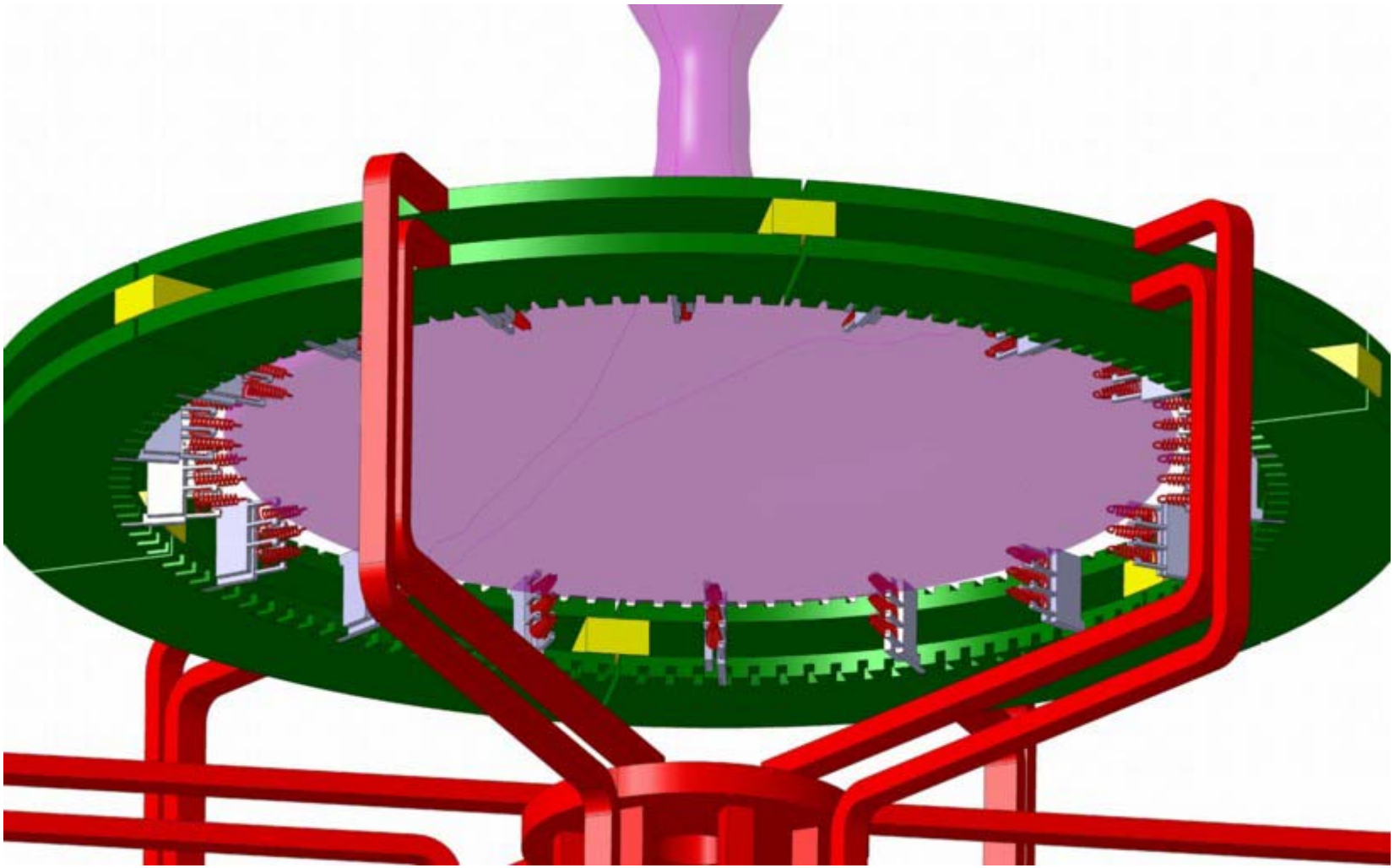
Definitive PROTO-SPHERA Anode

Possibility of arc anchoring ⇒ needs of saddle coils?

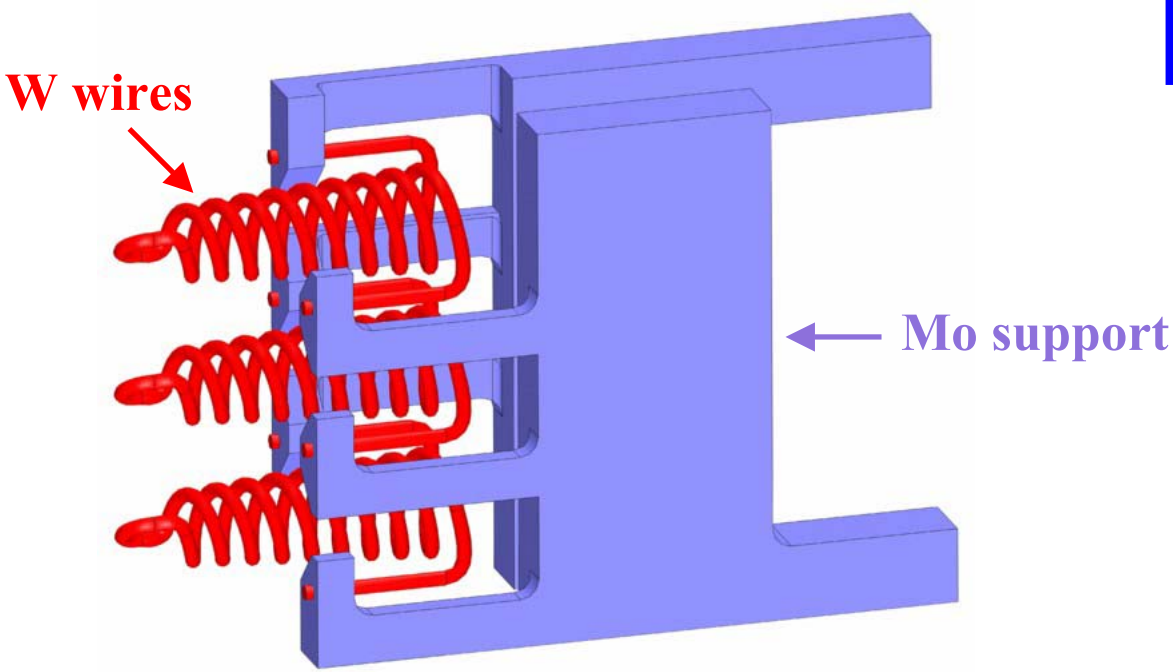


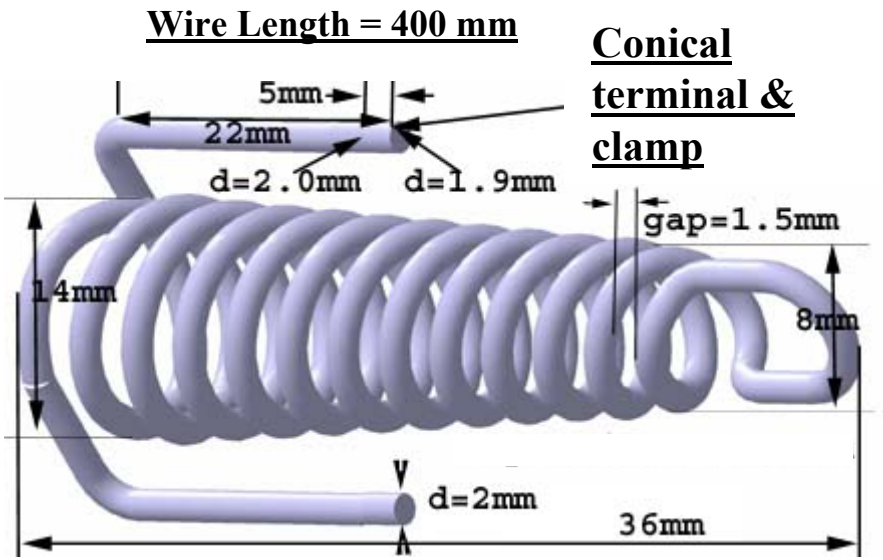
Multi-Pinch Cathode

Definitive PROTO-SPHERA Cathode, but only partially filled



Multi-Pinch Cathode





- Multi-Pinch test is proposed with a limited number of cathode modules (18 Vs. 378)
- Wires will drive a limited total current (2.7 kA Vs. 60 kA) inside the pinch, simplifying the power supply for Multi-Pinch
- Each wire will be capable of delivering the design current (150 A)

Conclusions

- PROTO-SPHERA aims to explore the feasibility of a ST formed around a SP, with respect to the possibility to sustain it through Helicity Injection on resistive time scale
- An exhaustive range of PROTO-SPHERA scenarios has been investigated (resilience of the equilibria Vs. internal profile & ideal MHD stability boundaries)
- The Multi-Pinch experiment will investigate the feasibility of a stable mushroom-shaped Screw Pinch
- Multi-Pinch will be built inside the START vacuum vessel, PROTO-SPHERA can be obtained with a modular implementation of this experiment